



NASA SBIR 2015 Phase I Solicitation

Space Technology

Advanced Power and Energy Storage Systems for Cross-Cutting Space Applications Topic Z1

The Advanced Space Power and Energy Storage Systems topic area will focus on technologies that generate power and/or store energy within the space environment. Functional areas, sub-topics, of interest include:

Solid State Power Generation

Thermoelectric and thermionic component materials will be investigated for the creation of electricity from thermal energy in space applications. There is particular interest in high Z materials and materials with low work functions applicable to thermionic energy conversion. The focus of the topic area will be to generate working devices by the end of an SBIR Phase II. Material performance and testing may be the focus of the Phase I activity as long as explicit discussion of eventual working device is included in the Phase I proposal and the intent of the effort is to use Phase II follow on effort to build and test the working system.

Modeling and Simulation / Modeling and Measurements

Innovative model development to will provide insight into design decisions and trade-offs for advanced propulsion and power systems are sought. The focus is on improving the correlation between experiments and predictions by developing and validating multi-scale physics-based models. The goal is to reduce the development time of future systems needed for space exploration.

Sub Topics:

Z1.01 Modeling and Measurements for Propulsion and Power

Lead Center: GRC

Participating Center(s): ARC, JPL, MSFC

To reduce the development time of advanced future systems needed for space exploration, physics-based modeling tools are sought for:

- Electrochemical systems such as batteries, fuel cells and electrolyzers.
- Nuclear power and nuclear power based propulsion systems.
- Microfluidic electrospray propulsion systems.

In each case, the emphasis is on determining performance-limiting features and identifying potential means to overcome limitations. Models should focus on aspects of the system where interactions of sub-systems or components is poorly understood and where development frequently relies on heuristics or iterative build and test cycles to settle on designs. Electro-chemistry models are sought that predict the rates of reaction, or side products of a reaction, predicated upon the thermodynamic or kinetic properties of electrode and electrolyte materials are

needed. Nuclear systems models are required that model the fission reaction, heat transport, latent radiation, etc. in sufficient detail to predict design efficacy, evaluate engineering solutions, and reduce testing requirements. Creating interfaces between reactor models and engine system models, including radiation effects, and modeling nuclear thermal propulsion ground test engine exhaust filtering and containment are areas of particular interest. Physics based models are sought to predict flow properties of liquid metal or ionic liquids for microfluidic electrospray propulsion systems. Of particular interest are models that describe capillary flow forces as a function of micro-geometry, the characterization of end-to-end velocity profiles in a feed system, viscosity and velocity characterization as a function of thermal gradients, the boundary between flow characteristics determined by microfluidic capillary forces and flow characteristics determined by formation and operation of Taylor cones, and fluid properties under steady state and pulsed electric operation at the boundary of Taylor cones. Model validation will also be required; improved measurement techniques needed for validation are also of interest provided they are coupled with a modeling activity outlined above. Tools that exclusively model proprietary systems will not be considered for award.

Z1.02 Solid-State Thermal-to-Electric Power Generation

Lead Center: JPL

Participating Center(s): GRC, JSC

Future NASA missions require power generation capabilities beyond what can be easily supported using solar arrays or chemical fuel cells. Thermal-to-Electric materials and systems working in conjunction with nuclear systems have the potential to serve this need and to operate at distances from the Sun well beyond the limit of its useful energy. Existing Thermal-to-Electric materials and systems do not “trade well” with existing power generation options, e.g., fuel cells, due to poor efficiency and specific power, however their longevity of operation makes them attractive for many other mission spaces. In the last decade extensive research has gone into raising the figure of merit for thermoelectric materials, ZT , both new materials and new fabrication techniques that modify the morphology and atomic lattice of the materials, have been attempted with varying degrees of success. Simultaneously, work has been done on creating “coupled” systems similar to multi-junction solar arrays that produce greater efficiency than single layer systems. Although this research has resulted in significant advances at the basic materials level, these advances have yet to be transitioned to NASA RTGs. In fact the Mars Curiosity MMRTG utilized the same TE materials and reported the same system level performance, i.e., efficiency and specific power, as the SNAP 19 RTG launched in 1972 for Pioneer 10. Thermionic power conversion is a complimentary static approach which could extend power conversion efficiencies beyond thermoelectric limits to as high as 25% or more. Successful thermionic converters would enable power systems with the efficiency of dynamic systems (Rankine, Brayton and Stirling), but with no moving parts and the potential for high reliability. High waste heat rejection temperatures also lead to modest radiator area and mass. Thermionic converters received much attention in the 1960's-90's for solar and nuclear power, and were flown in space by the Russians in the 1990's. At the time, high-temperature low-work-function materials, precise gap maintenance, and space charge buildup proved problematic for the then state-of-art. Since the year 2000, major advances have been made in the highly relevant fields of nanotechnology, nanomaterials, MEMS, micromachining and fabrication, and new converter topologies. Proposals are thus solicited for application of these new ideas towards practical thermionic converters for nuclear and solar space power generation, and terrestrial topping cycles or energy harvesting.

This topic seeks to explore emerging capabilities in both Thermoelectric and Thermionic materials with an eye towards improving base system efficiencies and specific power of systems employing thermal to electric concepts. Proposals are solicited that focus on transitioning the improvements in bulk TE materials to system solutions for advanced power-generation and conversion technologies that will enable or enhance the capabilities of future science and human exploration missions. Requirements for these missions are varied and include long life, high reliability, significantly lower mass and volume, higher mass specific power, and improved efficiency over the state of practice for components and systems. Other desired capabilities are high radiation tolerance and the ability to operate in extreme environments (high and low temperatures and over wide temperature ranges). This topic will focus on:

- Advanced bulk materials enabling demonstration of high efficiency thermoelectric energy conversion (>15%) when using high grade space-qualified heat sources (> 1000 K).
- Advanced thermoelectric couple and module component technologies that will facilitate integration of new high performance materials into high reliability, high temperature long life systems.

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- Advanced high temperature ($>1500\text{ K}$) thermionic materials demonstrating low work function ($< 3\text{ eV}$) and high Richardson coefficient ($> 80\text{ Amps/cm}^2\text{-K}^2$) to enable high efficiency ($>25\%$) thermionic converters.
 - Advanced thermionic converter designs leveraging modern approaches in nanotechnology, nanomaterials, microfabrication, and/or novel system topologies which demonstrate the potential for high conversion efficiency ($> 25\%$).

Phase I products should include materials and proof-of-principle device-level demonstrations, test data, and conceptual system designs that incorporate the components advanced in Phase I and show a path to a successful Phase II project predicated on the criteria below.

Phase II should result in a working performance demonstrator at TRL 4 or greater, and should include a technology development plan for potential infusion into a flight system.

Lightweight Materials, Structures, and Advanced Manufacturing/Assembly Topic Z2

The Lightweight Materials, Structures, and Advanced Manufacturing/Assembly SBIR topic area will focus on technologies that will enable mass reduction, improved performance, lower cost and scalability of the material and structural systems that will be critical to NASA's space exploration and missions. As NASA strives to explore deeper into space than ever before, improvements in all of these areas will be critical. For example, mass reduction is an ever-present goal in the development of space exploration systems. Reductions in structural mass can either enable additional payload to be launched to orbit or reduce the mass of the payload that must be returned to Earth or landed on another planetary surface. Application areas for the material, structural, and manufacturing/assembly technologies developed under this SBIR topic include launch and crew vehicles, in-space transportation elements, habitation and crew-transfer systems, surface systems, and other systems used for space exploration.

Since this topic area has a broad range of interest, subtopics are selected by the Space Technology Mission Directorate to enhance and/or fill gaps in the exploration technology development programs and to complement other mission directorate topic areas. Advances in composite, metallic, and ceramic material systems are of interest in this topic, as are advances in the associated manufacturing methods for these various material systems. Significant advances can be realized by improvements in material formulation through improvements in the capabilities to manufacture and assemble large-scale structural components. Therefore, subtopics of interest will include but will not be limited to nanomaterial and nanostructures development, advanced metallic materials and processes development, and large-scale polymer matrix composite structures, materials, and manufacturing technologies. Other sub-topic areas may be added as required to address specific agency needs.

The subtopic of interest for FY15 addresses large-scale polymer matrix composite (PMC) structures and materials, and concentrates on developing lightweight structures using advanced materials technologies and new manufacturing processes. Out of autoclave material systems and processing as well as joining technologies to enable 5 – 9 m diameter composite structures will be of interest. The specific needs and metrics of this focus area is described in the subtopic description.

Research awarded under this topic should be conducted to demonstrate technical feasibility (proof of concept) during Phase I and show a path toward a Phase II hardware demonstration, and when possible, deliver a full-scale demonstration unit for functional and environmental testing at the completion of the Phase II contract.

References:

- (<http://www.nasa.gov/directorates/spacetech/home/index.html> [1]).

Sub Topics:

22.01 Large-Scale Polymer Matrix Composite (PMC) Structures, Materials, and Manufacturing Processes

Lead Center: MSFC

Participating Center(s): LaRC

The subtopic area for Large-Scale Polymer Matrix Composite (PMC) Structures and Materials concentrates on developing lightweight structures, using advanced materials technologies and new manufacturing processes. The objective of the subtopic is to advance technology readiness levels of PMC materials and manufacturing for launch vehicles and in-space applications resulting in structures having affordable, reliable, and predictable performance. A key to better understanding predictable performance and faster qualification of components includes integrating the analytical tools between the materials and manufacturing process.

The subtopic will focus efforts to enable large (5 to 9 meter) diameter composite structures. Specific areas of interest include advances in PMC high performing resin/fiber material systems and associated out-of-autoclave processes for the manufacturing of large composite structures and innovative low cost, high reliability composite joint concepts/techniques. Proposals to each area will be considered separately:

- Advances in PMC high performing resin/fiber systems which can be cured via out of autoclave processes (such as resin infusion, or equivalent) which will yield large complex composite structures. Properties for this material system should use IM7/8552-1 or IM7/977-2 toughened epoxy systems as a baseline goal. Acceptable properties are key, but end-to-end manufacturing process evaluation should be considered to support scale-up including integration of modeling and potential automation of the processes.
- Innovative low cost, high reliability composite joining concepts/techniques for attaching large segmented structures together. Concepts must consider end-to-end process evaluation with considerations to modeling of the joint/joining process and to full-size scale-up factors which will limit autoclave and oven access for joint cures. Concepts that are amenable to in-situ and/or on-orbit implementation are also of interest.

Research should be conducted to demonstrate novel approaches, technical feasibility, and basic performance characterization for large-scale PMC structures and joint concepts during Phase I, and show a path toward a Phase II design allowables and prototype demonstration. Emphasis should be on demonstrable manufacturing technology that can be scaled up for very large structures.

References:

- Kirsch, M. T., "Composite Crew Module: Primary Structure." (<http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110020665.pdf> [2]).
- Tenney, D. R. et al., "NASA Composite Materials Development: Lessons Learned and Future Challenges," (<http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090037429.pdf> [3]).
- "Composite Cryotank Technologies & Demonstration." (https://gcd.larc.nasa.gov/wp-content/uploads/2013/07/FS_CCTD_factsheet.pdf [4]).

Entry, Descent, and Landing Topic Z3

The Entry, Descent and Landing topic area will focus on technologies that enable EDL for NASA's challenging future planetary and Earth return missions. Functional areas, or subtopics, of interest include:

- *Engineering Instrumentation* - Sensors and sensor systems are needed, that will gather engineering data during EDL, for validating models, improving future missions, and generally advancing the state of the art. Sensors of interest include heatshield and backshell heating, pressure, radiometric and spectroscopic instruments, cameras for imaging critical events, and minimally-intrusive techniques such as wireless or acoustic systems. Key characteristics that are sought include: modularity; low mass, power, and volume; and minimal cost for the sensor system, which includes data acquisition, transfer, and storage.
- *Guidance and Control Techniques for EDL* - Advancements in hardware and software for autonomously guiding entry vehicles to specific landing sites will enable an increase in productive time on a planetary

surface, or allow aggregation of surface assets. Achieving virtually pinpoint landings may require modified vehicle shapes, control methods that operate in extreme environments, or other hardware innovations. Accompanying numerical algorithms need to efficiently and robustly manipulate the vehicle system through the hypersonic, supersonic, and subsonic flight regimes.

- *Advanced Materials* - This subtopic seeks specific materials innovations that are unique to EDL, including thermal protection systems, multifunctional structures, and inflatable and deployable decelerator concepts.
- *Modeling and Simulation* - Innovative M&S tools that will provide insight into system and subsystem performance, design decisions, and trade-offs are sought. Physics-based models that can facilitate a move towards computational validation, or models grounded in flight data, are particularly of interest. The focus is on the reduction of overall development time and cost for advanced future systems needed for space exploration.

Sub Topics:

Z3.01 Wireless Cameras for Entry, Descent, and Landing Reconstruction

Lead Center: JPL

Participating Center(s): LaRC

This subtopic seeks innovative solutions for the collection of high resolution, high frame rate, and low distortion imagery of key events and hardware during entry, descent, and landing. This would enable the capture of valuable forensic images for spacecraft events such as the deployment and inflation of parachutes, vehicle touchdown dynamics, and plume-ground interactions.

Because the intended usage of the camera system is during EDL, a series spacecraft critical events, the camera system must operate on a non-interference basis with the rest of the spacecraft. Additionally, the use of wireless cameras allows the cameras to be optimally placed to capture imagery of key hardware that may be difficult to access with traditional wired cameras.

Camera Sensor Performance Targets:

- Format and Frame Rate Minimum: 1080p @ 30 fps (up to 100 fps).
- Array Format Minimum: 1920 x 1080 Pixels.
- Target Wavelength Range: 480nm - 800nm (TBR).
- Windowing: Yes.
- Color: Yes.
- Technology: CMOS or CCD.
- Temperature Range: -30 °C to +40 °C.

Camera Optical Performance Targets:

- Field of View: +/- 45 degrees off center-line.
- Focus: 0.5 m to infinity.

Supporting Avionics Functions:

- Ability to control the camera sensor.
- Ability to (near) real time, receive and store seconds to a few minutes of data at the above frame rates, then transmit the image data to the main entry vehicle computer.
- Distance from camera to storage device is between 0.5-10 meters.
- Unit volume no greater than 12.7 cm x 12.7 cm x 12.7 cm.

Phase I Deliverables- Include a camera system architecture design, and a testing and calibration plan. Constructing a breadboard unit would also be desired.

Phase II Deliverables - Include an engineering-level prototype system on which the testing and calibration from Phase I would have been completed, and a test/performance report.

Small Spacecraft Technology Topic Z4

This topic seeks innovative technologies for components and subsystems for small spacecraft ranging in size from cubesat-scale up to approximately 100 kilograms in mass. These spacecraft are intended for science, exploration, and other missions in Earth orbit and in regions of the inner solar system beyond Earth.

Proposals are sought for projects that can produce, by the end of Phase II, flight-quality hardware or at least proto-flight hardware for the designated components or subsystems that might then be integrated into spacecraft for technology demonstration flights. Several specific technology areas are of interest in this solicitation:

- Solar arrays, energy storage, and integrated power systems for small spacecraft. The primary power requirement is for electric propulsion systems although these spacecraft might also utilize significant electrical power for communications and payload operations.
- Navigation and attitude determination systems for small spacecraft operating beyond low-Earth orbit to provide precise knowledge of the spacecraft state (position, attitude, and rates in all axes) without reliance on the Global Positioning System or similar Earth-orbit references or planetary magnetic fields.
- Structural design concepts for small spacecraft that offer significant advantages over conventional structures in one or more of the following ways:
 - Reduce mass while maintaining adequate strength.
 - Provide thermal management features for the spacecraft such as enhanced heat transfer and heat rejection.
 - Provide radiation shielding to other spacecraft components.
 - Enhance the ease of assembly and integration of spacecraft.

Sub Topics:

Z4.01 Small Spacecraft in Deep Space: Power, Navigation, and Structures

Lead Center: ARC

This subtopic seeks innovative technologies for components and subsystems for small spacecraft ranging in size from cubesat-scale up to spacecraft of approximately 100 kilograms in mass. These spacecraft are intended for science, exploration, and other missions in Earth orbit and, in particular, for operations in other regions of the inner solar system beyond Earth.

For all technology areas outlined below, the components and subsystems must be tolerant of typical launch vehicle loads and environments and operationally tolerant of the thermal and radiation environment that exists, as a minimum, in earth orbit at any altitude above 300 km, in cis-lunar space including lunar orbit, and in heliocentric orbit at 1 Astronomical Unit (AU) from the sun. It is desirable that these components and subsystems also be operationally tolerant of the thermal and radiation environment that exists in interplanetary space ranging from 0.7 AU to at least to 3 AU from the sun and in orbit around Mars and Venus. Components and subsystems must also be resistant to the atomic oxygen environment in low-Earth orbit.

For all technology areas below, proposals are sought for projects that can produce, by the end of Phase II, flight-quality hardware or at least proto-flight hardware for the designated components or subsystems that might then be integrated into spacecraft for technology demonstration flights, initially in low-Earth orbit. Initial flight demonstrations are likely to employ 3-unit or 6-unit cubesat spacecraft. For convenience in integration, components and subsystems should be designed to fit a standard cubesat unit (10 by 10 by 10 centimeters), a fraction of that unit, or multiples of that unit. The desired Phase I deliverables include a detailed description and plan for development and fabrication of the hardware to be produced by the end of Phase II.

Proposals are sought in several technology areas outlined below. Proposers should clearly state the technology area addressed by their proposal. Proposers may submit more than one proposal but each individual proposal must address only one of the technology areas below.

Power Systems for Small Spacecraft

This area seeks innovative technologies for solar power generation and/or electrical energy storage systems for small spacecraft ranging in size from cubesat-scale up to spacecraft of approximately 100 kilograms in mass. The primary power requirement is for electric propulsion systems although these spacecraft might also utilize significant electrical power for communications and payload operations.

- **Solar Array Systems:** Solar array systems consisting of deployable panels or blankets with necessary structural support, mechanisms, and functional photovoltaic cell arrays. The arrays must be designed for unaided deployment in the space environment (micro-gravity and vacuum conditions) and provide for functional power generation. Innovations are sought in compact packaging of arrays for launch, reliable array deployment at a specified time after launch, and reliable power generation in space. Systems with low mass are desired but compact storage volume is the more important feature. The power generation goal for these systems is 100 to 500 watts per panel (power at beginning of life at 1 AU from the sun) for panels that can be packaged for launch within a volume of three cubesat units (3U) or less. Systems are sought which also incorporate the capability for rotation relative to the body of the spacecraft to allow the array to track the sun as the spacecraft moves through space.
- **Energy Storage Systems:** Batteries or other types of rechargeable energy storage systems with a capacity of 200 to 2000 watt-hours and with minimum volume and mass. Functional heat rejection requirements must also be addressed in the design and prototype hardware.
- **Integrated Power Systems:** Systems that include the solar array and energy storage as a system, ready for integration into a small spacecraft.

Navigation and Attitude Determination for Small Spacecraft beyond Earth Orbit

This area seeks innovative technologies for navigation and attitude determination systems for small spacecraft ranging in size from cubesat-scale up to spacecraft of approximately 100 kilograms in mass, operating beyond low-Earth orbit. The relevant systems are required to provide precise knowledge of the spacecraft state (position, attitude, and rates in all axes) without reliance on the Global Positioning System or similar Earth-orbit references or planetary magnetic fields. Any reliance on Earth based communications and tracking systems must take into account the limited power and other capabilities of small spacecraft operating at great distances from Earth. Novel concepts that minimize reliance on conventional navigation and tracking resources and techniques are desired.

The relevant navigation systems must be scaled for integration in small spacecraft with a target peak-power requirement of less than 100 watts and a volume of less than 3 cubesat units (approximately 10 by 10 by 30 centimeters) for the system. Lower volume, mass, and power usage is desirable. Requirements for heat rejection from the navigation system must be addressed in the design.

Structures for Small Spacecraft

This area seeks innovative technologies for structural designs for small spacecraft ranging in size from cubesat-scale up to spacecraft of approximately 100 kilograms in mass, for operation in and beyond Earth orbit. Structures for cubesats in the 3U, 6U and 12U size range are of particular interest. Proposed concepts should offer significant advantages over conventional aluminum or composite structures in one or more of the following ways:

- Reduce mass while maintaining adequate strength.
- Provide thermal management features for the spacecraft such as enhanced heat transfer and heat rejection.
- Provide radiation shielding to other spacecraft components.
- Enhance the ease of assembly and integration of spacecraft.

The recurring cost of the structures and materials proposed should be consistent with the low-cost goals of small

spacecraft projects.

Proposals must focus on the design and fabrication of flight-quality or at least proto-flight structures that might then be integrated into small spacecraft for technology demonstration flights. Proposals that address general innovations in advanced manufacturing, structures, or materials are not appropriate for this subtopic.

NASA Small Spacecraft Technology Program:

- (http://www.nasa.gov/directorates/spacetech/small_spacecraft/index.html [5]).

Small Spacecraft Technology State of the Art Report:

- (http://www.nasa.gov/sites/default/files/files/Small_Spacecraft_Technology_State_of_the_Art_2014.pdf [6]).

Assistive Free-Flyers Topic Z5

The Assistive Free-Flyers (AFF) topic area focuses on technology to enhance the capabilities and performance of small, free-flying robots that assist humans. AFF's can complement astronauts in space by performing tasks that are tedious, highly repetitive, dangerous or long-duration. AFF's can also provide side-by-side assistance to astronauts by carrying tools/materials, providing procedure support, etc.

AFF's can potentially be applied to a wide variety of tasks including in-flight maintenance, spacecraft health-management, environmental monitoring surveys (air quality, radiation, lighting, sound levels, etc.), and automated logistics management (inventory, inspection, etc.).

AFF's can be used when humans are present to off-load routine work, to increase human productivity, and to handle contingencies. AFF's can also be used when humans are not present, such as during "pre-deployment" and quiescent periods, to perform spacecraft caretaking. In particular, AFF's could be used to enable mobile monitoring, maintenance, and repair of spacecraft before, and between, crews.

Sub Topics:

Z5.01 Payload Technologies for Assistive Free-Flyers

Lead Center: ARC

Participating Center(s): JPL, JSC

The objective of this subtopic is to develop technology that can be integrated as external payloads on assistive free-flyers (AFF). AFFs are small free-flying robots that assist humans in exploration, surveillance, inspection, mapping, and other work. Current AFFs include space free-flyers, micro UAVs, drones, etc. A key characteristic of AFFs is that they can perform assistive tasks while co-located in human environments. On the International Space Station (ISS), for example, the SPHERES robots have shown how AFF's can perform environment surveys, inspection, and crew support.

During 2015-2017, STMD will develop a new AFF as part of the Human Exploration Telerobotics 2 (HET-2) project. This new robot will carry out inventory, sound monitoring, and other routine tasks on the ISS. Proposals are sought to create AFF payloads that can be integrated for application-specific functions, or that can provide general capability enhancements in three areas:

- **Sensor Payloads** - Compact sensors that can be used for environment monitoring, including detection of combustibles, air quality (CO₂ levels), illumination (light spectrum), radiation, etc.
- **Logistics Devices** - Devices that facilitate automated logistics management, particularly inventory scanners (RFID, barcode, etc.) and mechanisms to support tagging/tracking.

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- Appendages - Mechanisms that can be used for docking/perching, prodding/pushing, etc. This includes deployable structures, universal end-effectors (e.g., jamming granular gripper), and devices incorporating gecko or electrostatic adhesion.

Deliverables to NASA:

- Identify scenarios and use cases.
- Develop concepts.
- Construct prototypes.
- Perform technology demos.

Proposals are highly-encouraged that leverage the SPHERES engineering units and HET-2 free-flyers at the NASA Ames Research Center. Phase II efforts should deliver documentation and sufficient units to support future research/testing on ISS.

Advanced Metallic Materials and Processes Innovation Topic Z6

NASA is using several manufacturing processes supporting the Space Launch System to create structures with superior mechanical properties and increased reliability. Advancing the state of the art for advanced metallic materials and processes will continue to be a critical technology to build more efficient space vehicles with less expensive materials.

This topic seeks to develop new and innovative materials and manufacturing processes (both additive and subtractive) for lightweight and/or multifunctional metallic components and structures for NASA and related applications. Technologies that can enable joining of new or dissimilar materials, as well as significantly reduce costs, increase production rates, and improve weld quality should be considered.

Technologies should result in components with minimal or no machining; Technologies should provide novel techniques for producing high-strength components and joints that are highly free of defects. Emphasis on reduced structural mass, improves processing lead-time, and minimizes touch labor and final assembly steps, resulting in increased capability, reliability and reduced cost.

Sub Topics:

Z6.01 Advanced Metallic Materials and Processes Innovation

Lead Center: MSFC

Participating Center(s): JPL, LaRC

This subtopic seeks innovative processes and development of metallic material systems. This subtopic has an emphasis on solid state welding practices including but not limited to: ultrasonic, thermal, and friction stir welding; new concepts for built up structure approaches for lightweight structural panel applications, advanced near-net shaping, additive manufacturing processes; advanced coating technologies for wear and environmental resistance; functionally-graded (gradient alloy) materials that exhibit superior performance exceeding that of the individual constituent alloys. Technologies should result in components with minimal or no machining.

Proposals are sought in the following areas:

- Joining new materials: technologies that enable welding on a wide range of alloys and a wide range of thicknesses, including high-strength, temperature-resistant materials (such as titanium alloys, inconels, steels, and copper), metal-matrix composites, and other materials previously considered unweldable.
- Joining of complex geometries: technologies that enable welding of complex curvature joints or other types of structure variations that increase manufacturing possibilities.
- Development and prototyping technologies for fabricating gradient alloy (functionally graded) or amorphous (bulk metallic glass) materials for solid state welding processes, near-net shape, and additive

manufacturing processes.

Responses should identify key performance parameters and TRL advancement in terms of quantifiable benefits to address specific areas including but not limited to the following: reduced structural mass, increased structural efficiency, improved processing lead-time, minimized touch labor and final assembly steps, increased reliability and reduced cost. Scale-up and transition to aerospace hardware and products should also be addressed.

Modeling and Measurements for Propulsion and Power Topic Z1.01

To reduce the development time of advanced future systems needed for space exploration, physics-based modeling tools are sought for:

- Electrochemical systems such as batteries, fuel cells and electrolyzers.
- Nuclear power and nuclear power based propulsion systems.
- Microfluidic electrospray propulsion systems.

In each case, the emphasis is on determining performance-limiting features and identifying potential means to overcome limitations. Models should focus on aspects of the system where interactions of sub-systems or components is poorly understood and where development frequently relies on heuristics or iterative build and test cycles to settle on designs. Electro-chemistry models are sought that predict the rates of reaction, or side products of a reaction, predicated upon the thermodynamic or kinetic properties of electrode and electrolyte materials are needed. Nuclear systems models are required that model the fission reaction, heat transport, latent radiation, etc. in sufficient detail to predict design efficacy, evaluate engineering solutions, and reduce testing requirements. Creating interfaces between reactor models and engine system models, including radiation effects, and modeling nuclear thermal propulsion ground test engine exhaust filtering and containment are areas of particular interest. Physics based models are sought to predict flow properties of liquid metal or ionic liquids for microfluidic electrospray propulsion systems. Of particular interest are models that describe capillary flow forces as a function of micro-geometry, the characterization of end-to-end velocity profiles in a feed system, viscosity and velocity characterization as a function of thermal gradients, the boundary between flow characteristics determined by micro-fluidic capillary forces and flow characteristics determined by formation and operation of Taylor cones, and fluid properties under steady state and pulsed electric operation at the boundary of Taylor cones. Model validation will also be required; improved measurement techniques needed for validation are also of interest provided they are coupled with a modeling activity outlined above. Tools that exclusively model proprietary systems will not be considered for award.

Sub Topics:

Solid-State Thermal-to-Electric Power Generation Topic Z1.02

Future NASA missions require power generation capabilities beyond what can be easily supported using solar arrays or chemical fuel cells. Thermal-to-Electric materials and systems working in conjunction with nuclear systems have the potential to serve this need and to operate at distances from the Sun well beyond the limit of its useful energy. Existing Thermal-to-Electric materials and systems do not “trade well” with existing power generation options, e.g., fuel cells, due to poor efficiency and specific power, however their longevity of operation makes them attractive for many other mission spaces. In the last decade extensive research has gone into raising the figure of merit for thermoelectric materials, ZT, both new materials and new fabrication techniques that modify the morphology and atomic lattice of the materials, have been attempted with varying degrees of success. Simultaneously, work has been done on creating “coupled” systems similar to multi-junction solar arrays that produce greater efficiency than single layer systems. Although this research has resulted in significant advances at the basic materials level, these advances have yet to be transitioned to NASA RTGs. In fact the Mars Curiosity MMRTG utilized the same TE materials and reported the same system level performance, i.e., efficiency and specific power, as the SNAP 19 RTG launched in 1972 for Pioneer 10. Thermionic power conversion is a complimentary static approach which could extend power conversion efficiencies beyond thermoelectric limits to as high as 25% or more. Successful thermionic converters would enable power systems with the efficiency of dynamic systems (Rankine, Brayton and Stirling), but with no moving parts and the potential for high reliability. High waste heat rejection temperatures also lead to modest radiator area and mass. Thermionic converters received much attention in the 1960's-90's for solar and nuclear power, and were flown in space by the Russians in the 1990's. At the time, high-temperature low-work-function materials, precise gap maintenance, and space charge buildup proved problematic for the then state-of-art. Since the year 2000, major advances have been made in the highly relevant fields of nanotechnology, nanomaterials, MEMS, micromachining and fabrication, and new converter topologies. Proposals are thus solicited for application of these new ideas towards practical thermionic converters

for nuclear and solar space power generation, and terrestrial topping cycles or energy harvesting.

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- Advanced thermoelectric couple and module component technologies that will facilitate integration of new high performance materials into high reliability, high temperature long life systems.
- Advanced high temperature (>1500 K) thermionic materials demonstrating low work function (< 3 eV) and high Richardson coefficient (> 80 Amps/cm²-K²) to enable high efficiency (>25%) thermionic converters.
- Advanced thermionic converter designs leveraging modern approaches in nanotechnology, nanomaterials, microfabrication, and/or novel system topologies which demonstrate the potential for high conversion efficiency (> 25%).

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Phase II should result in a working performance demonstrator at TRL 4 or greater, and should include a technology development plan for potential infusion into a flight system.

Sub Topics:

Large-Scale Polymer Matrix Composite (PMC) Structures, Materials, and Manufacturing Processes Topic Z2.01
The subtopic area for Large-Scale Polymer Matrix Composite (PMC) Structures and Materials concentrates on developing lightweight structures, using advanced materials technologies and new manufacturing processes. The objective of the subtopic is to advance technology readiness levels of PMC materials and manufacturing for launch vehicles and in-space applications resulting in structures having affordable, reliable, and predictable performance. A key to better understanding predictable performance and faster qualification of components includes integrating the analytical tools between the materials and manufacturing process.

The subtopic will focus efforts to enable large (5 to 9 meter) diameter composite structures. Specific areas of interest include advances in PMC high performing resin/fiber material systems and associated out-of-autoclave processes for the manufacturing of large composite structures and innovative low cost, high reliability composite joint concepts/techniques. Proposals to each area will be considered separately:

- Advances in PMC high performing resin/fiber systems which can be cured via out of autoclave processes (such as resin infusion, or equivalent) which will yield large complex composite structures. Properties for this material system should use IM7/8552-1 or IM7/977-2 toughened epoxy systems as a baseline goal. Acceptable properties are key, but end-to-end manufacturing process evaluation should be considered to support scale-up including integration of modeling and potential automation of the processes.
- Innovative low cost, high reliability composite joining concepts/techniques for attaching large segmented structures together. Concepts must consider end-to-end process evaluation with considerations to modeling of the joint/joining process and to full-size scale-up factors which will limit autoclave and oven access for joint cures. Concepts that are amenable to in-situ and/or on-orbit implementation are also of interest.

Research should be conducted to demonstrate novel approaches, technical feasibility, and basic performance characterization for large-scale PMC structures and joint concepts during Phase I, and show a path toward a Phase II design allowables and prototype demonstration. Emphasis should be on demonstrable manufacturing technology that can be scaled up for very large structures.

References:

- Kirsch, M. T., "Composite Crew Module: Primary Structure." (<http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110020665.pdf> [2]).
- Tenney, D. R. et al., "NASA Composite Materials Development: Lessons Learned and Future Challenges," (<http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090037429.pdf> [3]).
- "Composite Cryotank Technologies & Demonstration." (https://gcd.larc.nasa.gov/wp-content/uploads/2013/07/FS_CCTD_factsheet.pdf [4]).

Sub Topics:

Wireless Cameras for Entry, Descent, and Landing Reconstruction Topic Z3.01

This subtopic seeks innovative solutions for the collection of high resolution, high frame rate, and low distortion imagery of key events and hardware during entry, descent, and landing. This would enable the capture of valuable forensic images for spacecraft events such as the deployment and inflation of parachutes, vehicle touchdown dynamics, and plume-ground interactions.

Because the intended usage of the camera system is during EDL, a series spacecraft critical events, the camera system must operate on a non-interference basis with the rest of the spacecraft. Additionally, the use of wireless cameras allows the cameras to be optimally placed to capture imagery of key hardware that may be difficult to access with traditional wired cameras.

Camera Sensor Performance Targets:

- Format and Frame Rate Minimum: 1080p @ 30 fps (up to 100 fps).
- Array Format Minimum: 1920 x 1080 Pixels.
- Target Wavelength Range: 480nm - 800nm (TBR).
- Windowing: Yes.
- Color: Yes.
- Technology: CMOS or CCD.
- Temperature Range: -30 °C to +40 °C.

Camera Optical Performance Targets:

- Field of View: +/- 45 degrees off center-line.
- Focus: 0.5 m to infinity.

Supporting Avionics Functions:

- Ability to control the camera sensor.
- Ability to (near) real time, receive and store seconds to a few minutes of data at the above frame rates, then transmit the image data to the main entry vehicle computer.
- Distance from camera to storage device is between 0.5-10 meters.
- Unit volume no greater than 12.7 cm x 12.7 cm x 12.7 cm.

Phase I Deliverables- Include a camera system architecture design, and a testing and calibration plan. Constructing a breadboard unit would also be desired.

Phase II Deliverables - Include an engineering-level prototype system on which the testing and calibration from Phase I would have been completed, and a test/performance report.

Sub Topics:

Small Spacecraft in Deep Space: Power, Navigation, and Structures Topic Z4.01

This subtopic seeks innovative technologies for components and subsystems for small spacecraft ranging in size from cubesat-scale up to spacecraft of approximately 100 kilograms in mass. These spacecraft are intended for

science, exploration, and other missions in Earth orbit and, in particular, for operations in other regions of the inner solar system beyond Earth.

For all technology areas outlined below, the components and subsystems must be tolerant of typical launch vehicle loads and environments and operationally tolerant of the thermal and radiation environment that exists, as a minimum, in earth orbit at any altitude above 300 km, in cis-lunar space including lunar orbit, and in heliocentric orbit at 1 Astronomical Unit (AU) from the sun. It is desirable that these components and subsystems also be operationally tolerant of the thermal and radiation environment that exists in interplanetary space ranging from 0.7 AU to at least to 3 AU from the sun and in orbit around Mars and Venus. Components and subsystems must also be resistant to the atomic oxygen environment in low-Earth orbit.

For all technology areas below, proposals are sought for projects that can produce, by the end of Phase II, flight-quality hardware or at least proto-flight hardware for the designated components or subsystems that might then be integrated into spacecraft for technology demonstration flights, initially in low-Earth orbit. Initial flight demonstrations are likely to employ 3-unit or 6-unit cubesat spacecraft. For convenience in integration, components and subsystems should be designed to fit a standard cubesat unit (10 by 10 by 10 centimeters), a fraction of that unit, or multiples of that unit. The desired Phase I deliverables include a detailed description and plan for development and fabrication of the hardware to be produced by the end of Phase II.

Proposals are sought in several technology areas outlined below. Proposers should clearly state the technology area addressed by their proposal. Proposers may submit more than one proposal but each individual proposal must address only one of the technology areas below.

Power Systems for Small Spacecraft

This area seeks innovative technologies for solar power generation and/or electrical energy storage systems for small spacecraft ranging in size from cubesat-scale up to spacecraft of approximately 100 kilograms in mass. The primary power requirement is for electric propulsion systems although these spacecraft might also utilize significant electrical power for communications and payload operations.

- **Solar Array Systems:** Solar array systems consisting of deployable panels or blankets with necessary structural support, mechanisms, and functional photovoltaic cell arrays. The arrays must be designed for unaided deployment in the space environment (micro-gravity and vacuum conditions) and provide for functional power generation. Innovations are sought in compact packaging of arrays for launch, reliable array deployment at a specified time after launch, and reliable power generation in space. Systems with low mass are desired but compact storage volume is the more important feature. The power generation goal for these systems is 100 to 500 watts per panel (power at beginning of life at 1 AU from the sun) for panels that can be packaged for launch within a volume of three cubesat units (3U) or less. Systems are sought which also incorporate the capability for rotation relative to the body of the spacecraft to allow the array to track the sun as the spacecraft moves through space.
- **Energy Storage Systems:** Batteries or other types of rechargeable energy storage systems with a capacity of 200 to 2000 watt-hours and with minimum volume and mass. Functional heat rejection requirements must also be addressed in the design and prototype hardware.
- **Integrated Power Systems:** Systems that include the solar array and energy storage as a system, ready for integration into a small spacecraft.

Navigation and Attitude Determination for Small Spacecraft beyond Earth Orbit

This area seeks innovative technologies for navigation and attitude determination systems for small spacecraft ranging in size from cubesat-scale up to spacecraft of approximately 100 kilograms in mass, operating beyond low-Earth orbit. The relevant systems are required to provide precise knowledge of the spacecraft state (position, attitude, and rates in all axes) without reliance on the Global Positioning System or similar Earth-orbit references or planetary magnetic fields. Any reliance on Earth based communications and tracking systems must take into account the limited power and other capabilities of small spacecraft operating at great distances from Earth. Novel concepts that minimize reliance on conventional navigation and tracking resources and techniques are desired.

The relevant navigation systems must be scaled for integration in small spacecraft with a target peak-power requirement of less than 100 watts and a volume of less than 3 cubesat units (approximately 10 by 10 by 30

centimeters) for the system. Lower volume, mass, and power usage is desirable. Requirements for heat rejection from the navigation system must be addressed in the design.

Structures for Small Spacecraft

This area seeks innovative technologies for structural designs for small spacecraft ranging in size from cubesat-scale up to spacecraft of approximately 100 kilograms in mass, for operation in and beyond Earth orbit. Structures for cubesats in the 3U, 6U and 12U size range are of particular interest. Proposed concepts should offer significant advantages over conventional aluminum or composite structures in one or more of the following ways:

- Reduce mass while maintaining adequate strength.
- Provide thermal management features for the spacecraft such as enhanced heat transfer and heat rejection.
- Provide radiation shielding to other spacecraft components.
- Enhance the ease of assembly and integration of spacecraft.

The recurring cost of the structures and materials proposed should be consistent with the low-cost goals of small spacecraft projects.

Proposals must focus on the design and fabrication of flight-quality or at least proto-flight structures that might then be integrated into small spacecraft for technology demonstration flights. Proposals that address general innovations in advanced manufacturing, structures, or materials are not appropriate for this subtopic.

NASA Small Spacecraft Technology Program:

- (http://www.nasa.gov/directorates/spacetech/small_spacecraft/index.html [5]).

Small Spacecraft Technology State of the Art Report:

- (http://www.nasa.gov/sites/default/files/files/Small_Spacecraft_Technology_State_of_the_Art_2014.pdf [6]).

Sub Topics:

Payload Technologies for Assistive Free-Flyers Topic Z5.01

The objective of this subtopic is to develop technology that can be integrated as external payloads on assistive free-flyers (AFF). AFFs are small free-flying robots that assist humans in exploration, surveillance, inspection, mapping, and other work. Current AFFs include space free-flyers, micro UAVs, drones, etc. A key characteristic of AFFs is that they can perform assistive tasks while co-located in human environments. On the International Space Station (ISS), for example, the SPHERES robots have shown how AFF's can perform environment surveys, inspection, and crew support.

During 2015-2017, STMD will develop a new AFF as part of the Human Exploration Telerobotics 2 (HET-2) project. This new robot will carry out inventory, sound monitoring, and other routine tasks on the ISS. Proposals are sought to create AFF payloads that can be integrated for application-specific functions, or that can provide general capability enhancements in three areas:

- Sensor Payloads - Compact sensors that can be used for environment monitoring, including detection of combustibles, air quality (CO₂ levels), illumination (light spectrum), radiation, etc.
- Logistics Devices - Devices that facilitate automated logistics management, particularly inventory scanners (RFID, barcode, etc.) and mechanisms to support tagging/tracking.
- Appendages - Mechanisms that can be used for docking/perching, prodding/pushing, etc. This includes deployable structures, universal end-effectors (e.g., jamming granular gripper), and devices incorporating gecko or electrostatic adhesion.

Deliverables to NASA:

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- Identify scenarios and use cases.
 - Develop concepts.
 - Construct prototypes.
 - Perform technology demos.

Proposals are highly-encouraged that leverage the SPHERES engineering units and HET-2 free-flyers at the NASA Ames Research Center. Phase II efforts should deliver documentation and sufficient units to support future research/testing on ISS.

Sub Topics:

Advanced Metallic Materials and Processes Innovation Topic Z6.01

This subtopic seeks innovative processes and development of metallic material systems. This subtopic has an emphasis on solid state welding practices including but not limited to: ultrasonic, thermal, and friction stir welding; new concepts for built up structure approaches for lightweight structural panel applications, advanced near-net shaping, additive manufacturing processes; advanced coating technologies for wear and environmental resistance; functionally-graded (gradient alloy) materials that exhibit superior performance exceeding that of the individual constituent alloys. Technologies should result in components with minimal or no machining.

Proposals are sought in the following areas:

- Joining new materials: technologies that enable welding on a wide range of alloys and a wide range of thicknesses, including high-strength, temperature-resistant materials (such as titanium alloys, inconels, steels, and copper), metal-matrix composites, and other materials previously considered unweldable.
- Joining of complex geometries: technologies that enable welding of complex curvature joints or other types of structure variations that increase manufacturing possibilities.
- Development and prototyping technologies for fabricating gradient alloy (functionally graded) or amorphous (bulk metallic glass) materials for solid state welding processes, near- net shape, and additive manufacturing processes.

Responses should identify key performance parameters and TRL advancement in terms of quantifiable benefits to address specific areas including but not limited to the following: reduced structural mass, increased structural efficiency, improved processing lead-time, minimized touch labor and final assembly steps, increased reliability and reduced cost. Scale-up and transition to aerospace hardware and products should also be addressed.

Sub Topics:
